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PUBLICATIONS
V. Kiryukhin, E.P. Bernard, V.V. Khmelenko, R.E. Boltnev, N.V. Krainyukova, and D.M. Lee, "Noble-Gas Nanoclusters with Fivefold Symmetry Stabilized in Superfluid Helium," *Phys. Rev. Lett.*, **98**, 195506 (2007).

FUNDING
NASA
National Science Foundation
U.S. Civilian Research & Development Foundation

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Platonic Solids on the Nanoscale

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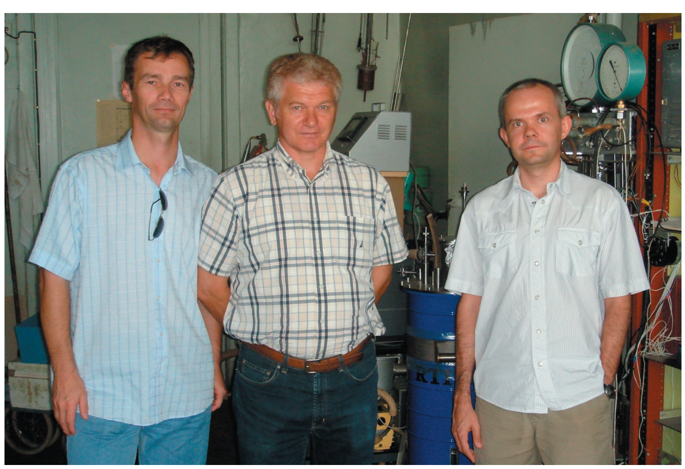
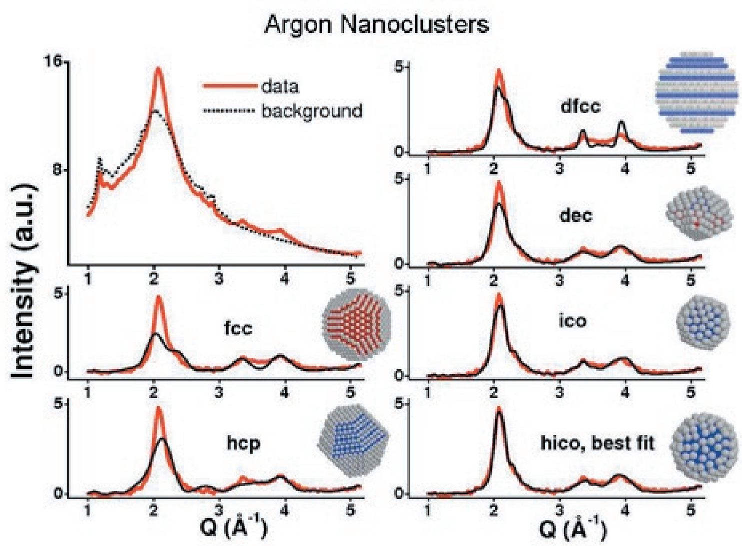
Nanometer-scale chunks of matter (nanoclusters) often possess properties that are very different from those of the bulk crystals. Understanding the behavior of nanoscale-patterned materials is necessary for technological progress in many areas, including electronics, data storage, and catalysis. Using synchrotron diffraction, it was for the first time demonstrated that bulk amounts of highly symmetric icosahedral and decahedral noble-gas nanoclusters can be produced by injecting the noble-gas atoms into superfluid helium. These results open new opportunities for fundamental and applied research of various nanoscale systems in previously unavailable quantities and in new experimental environments.

Growth of any solid from the liquid or gas phase begins with formation of small particles. The properties of such nanometer-scale particles, the nanoclusters, can be dramatically different from their macroscopic counterparts. This is true even for the simplest possible solids – those made of noble-gas atoms, such as neon and argon. Noble gases crystallize in the so-called face-centered cubic structure (fcc). However, due to surface energy effects, noble-gas nanoclusters are predicted to exhibit a variety of exotic shapes. The smallest clusters are expected to be icosahedral, the larger ones – decahedral, and even larger clusters should exhibit the hexagonal close-packed (hcp) structure. Such highly symmetric shapes are not coincidental. They result from the general principle of energy minimization requiring the densest possible packing of the attractive structural units combined with the minimum possible surface area. In other words, simple principles give rise to simple shapes. It is not, therefore, surprising that some of the famous Platonic solids, such as icosahedra and dodecahedra, spontaneously appear in the world of nanoparticles. Because of the generality of the underlying principles, such shapes are observed not only in inorganic systems. Some viruses and even higher organisms possess the shape of the Platonic solids.

Noble gases are important because of their simplicity: they are the best possible model systems to study. Noteworthy, even these simple systems are not understood completely. For example, the origin of the fcc structure in the bulk is currently unknown. It is, therefore, important to study noble-gas nanoclusters that are accessible to model calculations. For this, it is important to produce the clusters in bulk quantities. Until now, only minute quantities of icosahedral nanoclusters were produced in supersonic beams and on the surfaces. In this study, the nanoclusters were produced by injection of a helium jet with added noble-gas atoms into superfluid helium. As a result, bulk jelly-like samples were obtained. High-intensity x-ray beam from beamline X21, combined with the unique cryostat installed there, made it possible to determine the structure of these samples conclusively



Authors (from left) R.E. Boltnev, V.V. Khmelenko, and V. Kiryukhin for the first time. The samples were made of argon, krypton, and neon. They were found to consist of loose nanoclusters, 5-6 nanometer in diameter, suspended in liquid helium. Icosahedral and decahedral clusters were produced. Some of these results are shown in **Figure 1**. Importantly, bulk amounts of the nanoclusters were produced: the sample sizes exceeding 1 cm^3, and the atomic densities exceeding 10^{20} cm^{-3} were obtained. Thus, properties of the nanoclusters can now be studied with previously inaccessible techniques and in previously unattainable stable environments. Another key advantage of this technique is that the clusters can be made of a huge variety of materials, including technologically important magnetic materials, organic materials, water, and other important systems. These results open up numerous intriguing opportunities, and these studies are, therefore, only beginning.



X-ray diffraction data (red lines) and model calculations (black lines) for argon nanoclusters. Various structural models, including face-centered cubic (fcc), hexagonal close-packed (hcp), fcc with stacking faults (dfcc), decahedra (dec), icosahedra (ico), and icosahedra covered with one hexagonal overlayer (hico) are shown. The hico particles clearly describe the experimental data best for this sample.